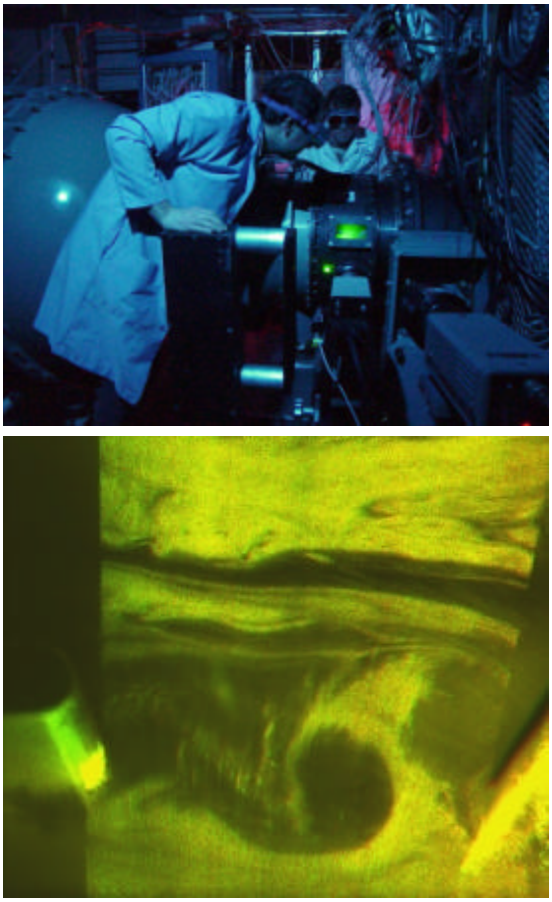
ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
May 2000

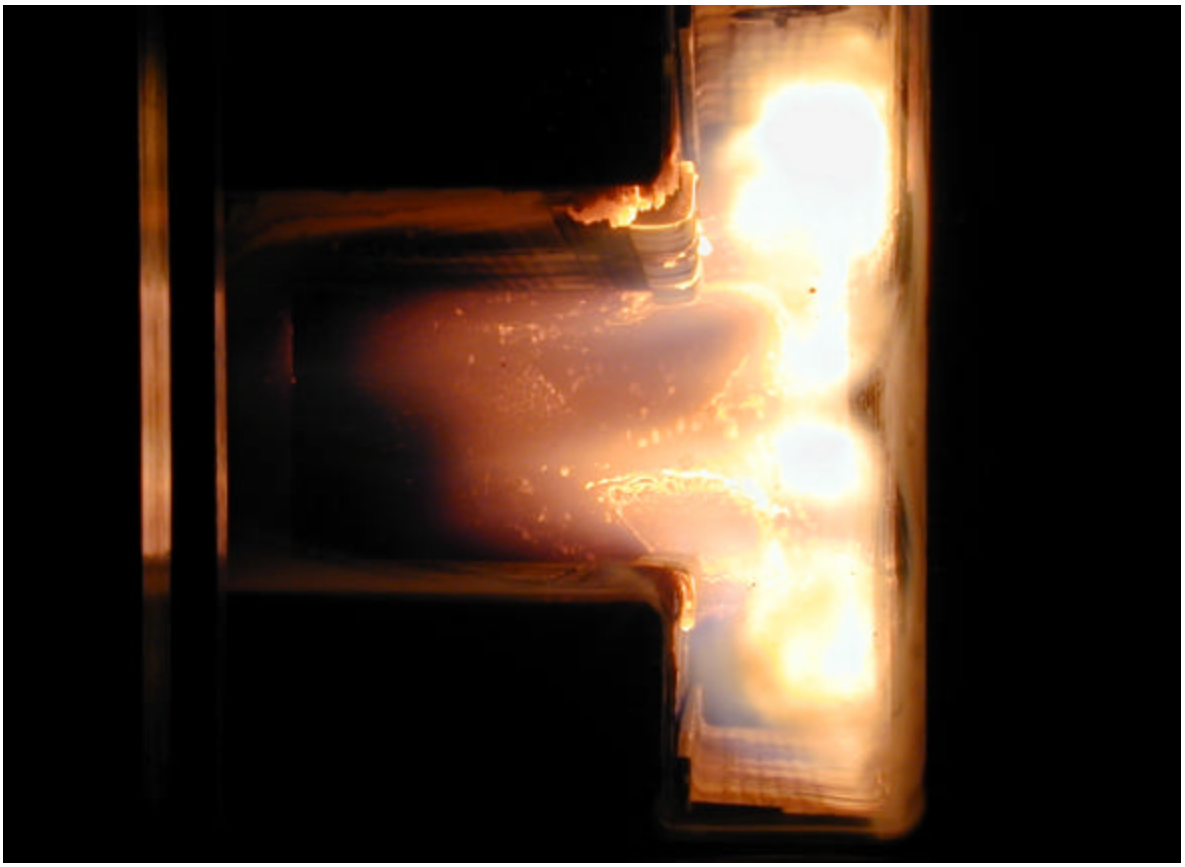
VISUALIZING COMPLEX COMPRESSOR FLOWS: A collaboration between Propulsion Directorate and Innovative Scientific Solutions Inc (ISSI) scientists has produced the world's first Particle Image Velocimetry (PIV) investigation of flow fields between closely-spaced blade rows in a transonic compressor. PIV images of a flow can be processed to yield kinematic properties such as velocity and vorticity. For the first time, investigators can obtain instantaneous information on the complex fluid interactions that occur in between blade rows in a turbine engine's compressor. This will provide the first understanding of the actual flow inside the compressor, and new insights into turbomachinery design methods are now possible as a result of this pioneering effort. These investigations were carried out in PR's Compressor Aero Research Lab (CARL). Researchers modified the CARL Stage Matching Investigation (SMI) rig by installing laser optics and a viewing window for digital photography. Future military engines will be designed with compressors whose blade rows will be closely spaced and highly loaded. Research at CARL has shown the potential for reductions in performance when blade row spacing is reduced, and it is critical that these unsteady influences be understood and properly accounted for in design. If these influences are not well understood, a greater potential will exist for performance reductions, blade fatigue, and increases in operational costs. Used as a benchmark for modeling and simulation code validation, this technique can significantly reduce maintenance costs through understanding and prevention of high cycle fatigue problems. (W. Copenhaver, AFRL/PRTF, (937) 255-7163)



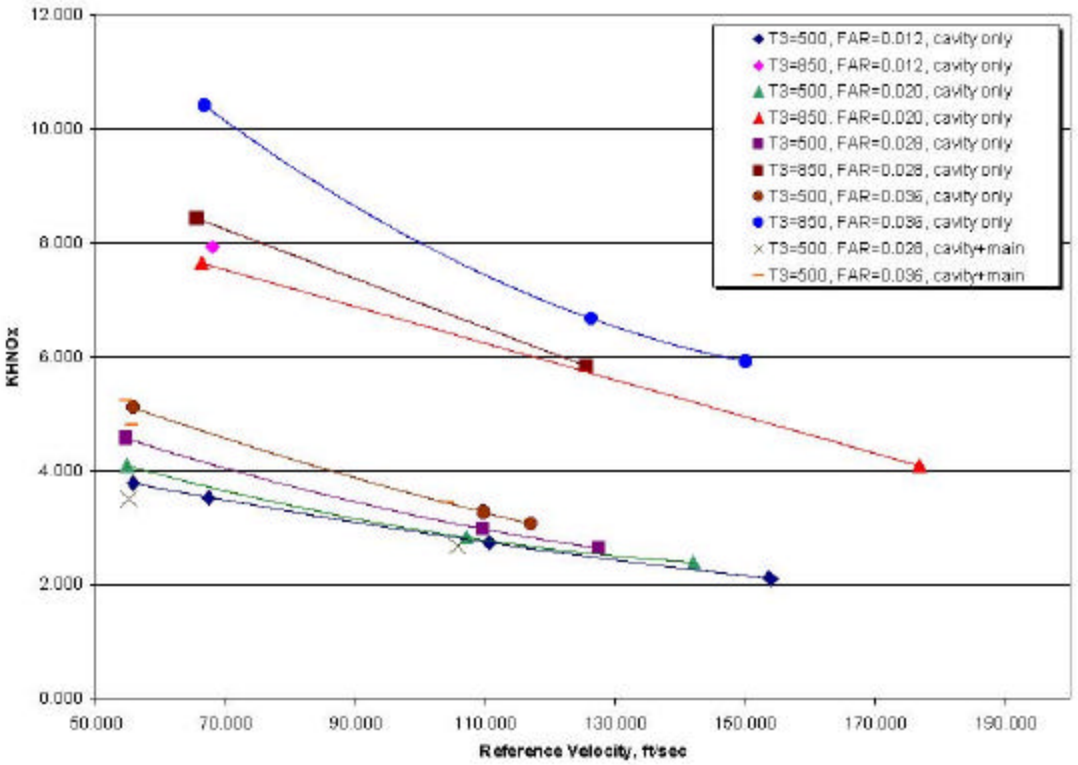
Investigations being conducted in PR's Compressor Aero Research Lab (top) and a PIV image (bottom)

TVC SUCCESSFULLY TESTED AT HIGHER MACH NUMBERS: In late April, researchers in the Propulsion Directorate's Combustion and High Speed Systems Branch (AFRL/PRSC), in collaboration with General Electric and NASA Glenn Research Center, completed testing of Configuration #6 of the 12-inch Trapped Vortex Combustor (TVC) Sector. The TVC is a unique turbine engine combustor concept that offers reduced emissions and improved performance in a small, simple, low cost package. The purpose of the latest testing was to examine the performance of the TVC at higher Mach numbers.

If the TVC can operate at higher Mach numbers, the combustor may be able to run without a diffuser thereby significantly reducing engine length and weight. In these joint tests, the TVC was operated at Mach numbers between 0.25 and 0.70. The overall equivalence ratio (a measure of the level of fueling) and the inlet air temperature were also varied over a wide range. Emissions and lean blow-out data were gathered during the testing, as well as video, photographs, and high speed movies. The TVC operated extremely well at these higher Mach numbers, and the increased flow velocity improved engine emissions. At a constant equivalence ratio, the NO_x emissions decreased by 33 to 50 percent while velocity was increased by a factor of two. The sensitivity of NO_x concentration to increasing flame temperature was also reduced by a factor of two with increasing velocity. Combustion efficiency and lean blow-out performance decreased only slightly with increasing flow velocity. (D. Shouse, AFRL/PRSC, (937) 255-4636)

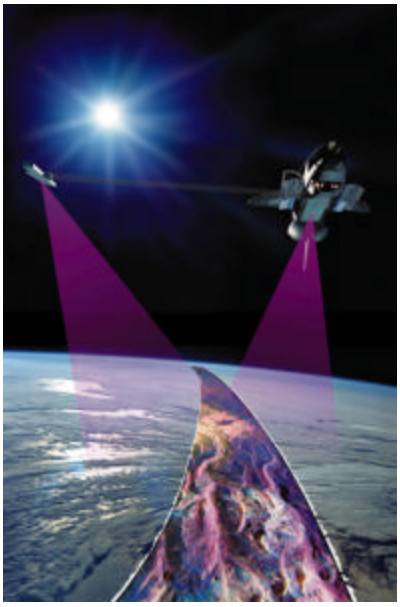


The Trapped Vortex Combustor in operation



The Trapped Vortex Combustor demonstrates a reduction in NO_x with increasing flow velocity

<u>200-FOOT LONG MAST USED FOR TOPOGRAPHY MISSION</u>: The 200-foot long Able Deployable Articulated Mast (ADAM™) for the Shuttle Radar Topography Mission (SRTM) was successfully deployed on 11 February 2000. The Survivable Power Subsystem (SUPER) Program, managed by the Propulsion Directorate's Power Division (AFRL/PRP), advanced technologies that enabled the development of ADAM™. ADAM™ was built by AEC-Able Engineering Company and carried into space aboard the Space Shuttle Endeavour (STS-99). The SRTM's mission was to map 70 to 80 percent of the Earth's landmass in three dimensions using an interferometric synthetic aperture radar. ADAM™ technology enables the SRTM system to perform at the high baseline precision necessary to achieve the desired mapping resolution. ADAM™ is the longest rigid structure ever to be deployed in space. The 605-pound mast's web of utility lines includes 440 pounds of coaxial and fiber-optic cables, stranded copper wire, and a single



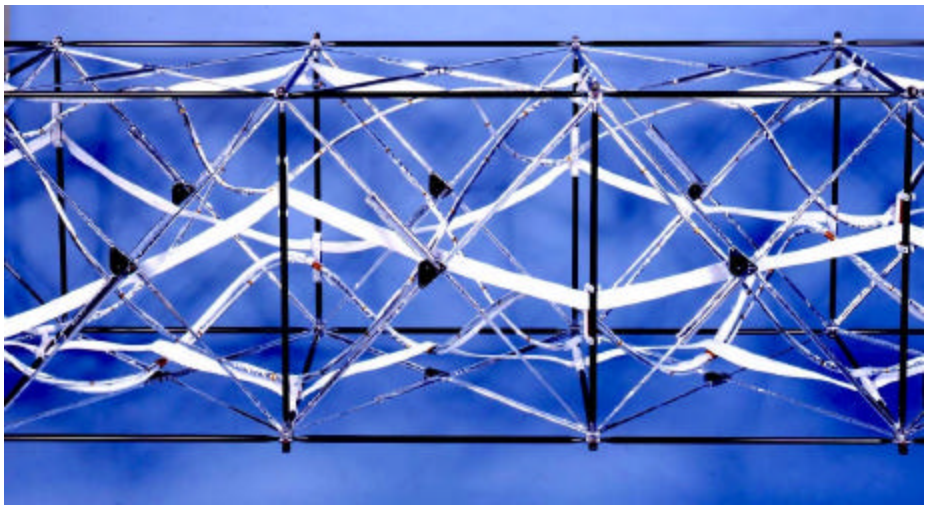
Artist's rendering of ADAM™ performing topography mission

thruster gas line. Remarkably, when stacked (including all cables) the mast fills a space just 56 inches wide or about 2 percent of its deployed length. The SRTM may not be the last flight for ADAM™ as talks are under way with NASA's Jet Propulsion Laboratory (JPL) for a re-fly. This technology has application to future Air Force Space Radar concepts that require large structures for solar arrays and reflectors. (G. Fronista, AFRL/PRPE, (937) 255-9392)

[See NASA's website for the SRTM at http://www.jpl.nasa.gov/srtm]

[To see an animation of the mast deployment, see AEC-Able's website at http://www.aec-able.com/corporate/srtm3.htm]

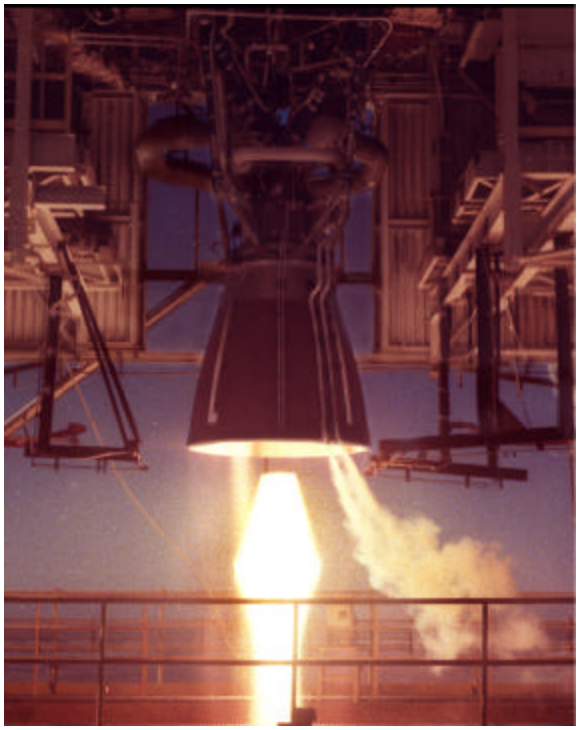
ADAM™ fully deployed (left) and deployed from Endeavour's bay (right)



Detail of ADAM™ structure and cabling

CONTINUED SUPPORT FOR RS-68 TESTING: The Propulsion Directorate continues to support testing of Boeing Rocketdyne's RS-68 rocket engine at Test Stand 1-A at Edwards AFB, California. The first large liquid-fueled rocket developed in the US since the Space Shuttle Main Engine (SSME), the RS-68 is the engine to power the new Delta IV/Evolved Expendable Launch Vehicle (EELV). The

EELV Program has a goal of reducing space launch costs by more than 25 percent, and achievement of this goal would make the RS-68 the lowest-cost American rocket engine ever produced in terms of dollars per pound of thrust. In prior testing at Edward AFB, the RS-68 set a record for the most thrust ever attained for a liquid oxygen/liquid hydrogen engine at more than 650,000 pounds. Several test firings of the RS-68 engine are scheduled this month at Edwards AFB, and the first RS-68 powered Delta IV launches are scheduled for FY02. (L. Quinn, AFRL/PRR, (661) 275-5630)

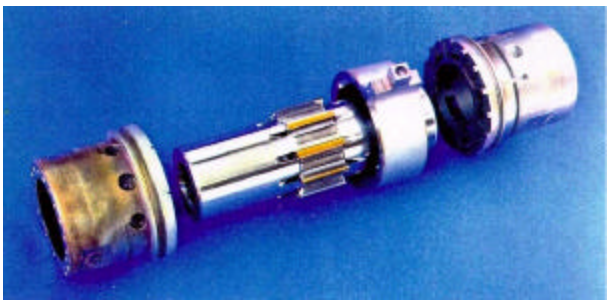


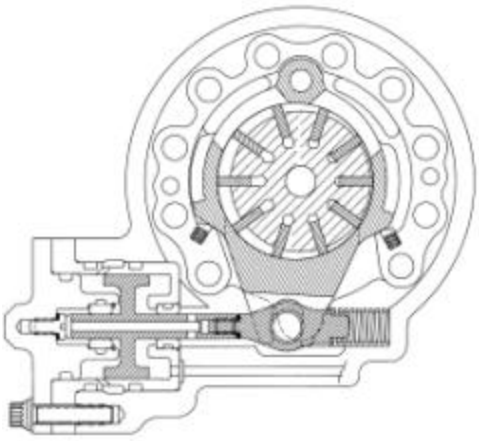
The RS-68 firing at Test Stand 1-A

PR PARTICIPATION KEY TO SYMPOSIUM SUCCESS: Propulsion Directorate participation was a key to the success of the 25th Annual Dayton-Cincinnati Aerospace Science Symposium held in Dayton, Ohio, on 30 March 2000. Sponsored by the American Institute for Aeronautics and Astronautics (AIAA), the purpose of this annual event is to facilitate communication between members of the local technical community. The executive co-chairs for this year's symposium were Dr. William Copenhaver of the Propulsion Directorate and Mr. Gary Dale of the Air Vehicles Directorate. Propulsion Directorate government and on-site contractor personnel chaired 14 of the 40 technical sessions featured at the symposium. Furthermore, of the nearly 180 presentations made at the symposium, 35 were co-authored by Propulsion Directorate government and on-site contractor personnel. A further highlight of the symposium was the keynote address titled "Emerging Propulsion Technologies for the 21st Century" presented by Dr. Edward T. Curran, former Director of the Propulsion Directorate. (J. Pearce, AFRL/PRO (UTC), (937) 255-5451)

VARIABLE DISPLACEMENT VANE PUMP TECH TRANSITION PLANNED: Representatives of the Air Force, General Electric Aircraft Engines, Chandler Evans Control Systems, and consultants familiar with the F100 pump recently met on the topic of Variable Displacement Vane Pumps (VDVPs). The purpose of this meeting was to identify risk reduction activities for the transition of a VDVP from AFRL to the Joint Strike Fighter (JSF) Program. Personnel from the Propulsion Directorate, ASC's Propulsion Development System Office (ASC/LP), and ASC's Engineering Directorate (ASC/EN) represented the Air Force. Due to experience gained with the original F100 engine main fuel pump, the VDVP is considered a high-risk technology. The F100 pump was designed to operate with unfiltered fuel that led to the selection of tungsten carbide, a very brittle material, for the vanes. This choice and other design characteristics resulted in a pump design that had both low reliability and low durability. As a result, it was determined that the catastrophic failure modes are adequately covered by the design, and that testing should be concentrated in other areas. These other areas include long-term durability

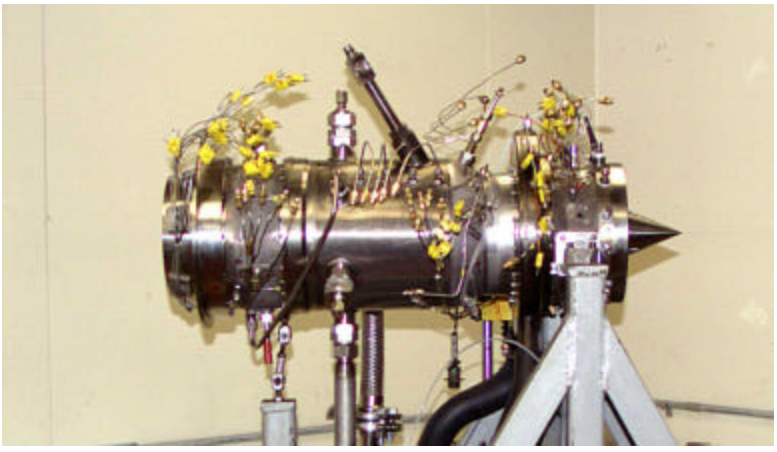
(endurance) testing, testing over the full range of anticipated operational conditions, pressure ripple testing, and testing control methods as a part of a fuel system. These technologies will be demonstrated on a JSF-like fuel system rig and on the XTC77/1. These demonstrations will significantly reduce the risk of the VDVP technology allowing for successful transition to the JSF Program at an acceptable technology readiness level. (D. Tasch, AFRL/PRTA, (937) 255-6690)





A Variable Displacement Vane Pump (top) and schematic (bottom)

IHPTET JETEC POISED TO CONTINUE TESTING: Williams International initiated testing of their Integrated High Performance Turbine Engine Technology (IHPTET) Phase II Joint Expendable Turbine Engine Concept (JETEC) demonstrator engine in January 1999. To date, this JETEC demonstrator has successfully completed over 25 hours of testing at Williams' facility. In the original plan, further demonstration tests at supersonic flight conditions were to be conducted at NASA Glenn Research Center (GRC). However, when an acceptable test window at NASA GRC could not be secured, the test was moved to Arnold Engineering Development Center (AEDC). Testing at AEDC will be initiated with a facility/demonstrator engine check-out on 16 May 2000. This test will incorporate the all metal hot section used in all testing to date. The demonstrator engine will then be reconfigured and tested with a ceramic hot section approximately 4 weeks later in mid-June. This final test will include a demonstration at simulated transonic and low supersonic flight conditions, as well as the demonstration of the IHPTET Phase II supersonic expendable goals of a 70 percent increase in FN/WA and a 45 percent decrease in production cost. (L. Chrisinger, AFRL/PRTP, (937) 255-2767)



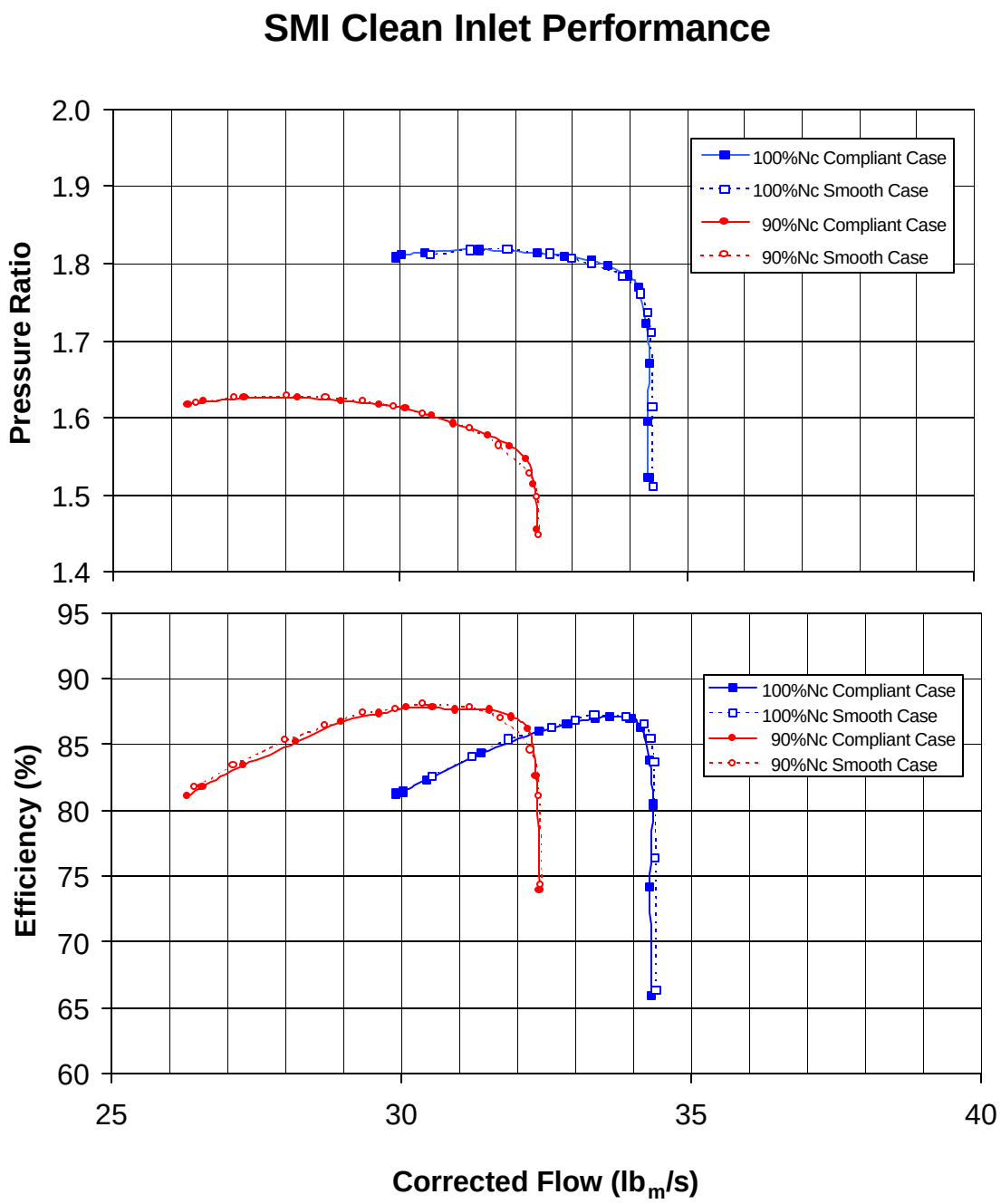
The Williams JETEC demonstrator engine

EFFORT TO DEVELOP HIGH TEMPERATURE LUBE AHEAD OF SCHEDULE: The Propulsion Directorate's in-house effort to develop a higher temperature lubricant is now about 8 months ahead of schedule. This project is a collaborative effort between the Propulsion Materials Application Branch (AFRL/PRSM) at Edwards AFB and the Lubrication (AFRL/PRSL) Branch at Wright-Patterson AFB. The main technical challenge of this project is to develop a lubricious fluid that has good flow properties at -40ºF and good thermal stability above 450ºF (ideally up to about 600ºF). Candidate lubricants are based on a combination of PRSM's polyhedral oligomeric silsesquioxane (POSS) and PRSL's ester lubricant technologies. PRSM researchers have succeeded in developing the first-ever POSS oils, which have the beneficial property of good flow at -40ºF. They have also developed a new ester that has higher thermal stability than the best turbine engine ester lubricants. The compounding of high potential esters with the POSS oils may lead to revolutionary new lubricant materials, either as basestock or high thermal stability additives. This combination of successful syntheses puts the project well ahead of schedule, as this level of progress was not expected until the end of 2000. Dr. Blanski's (AFRL/PRSM) brilliant synthesis work on this project has led to the nomination of this project as the Propulsion Directorate's In-House Project of the Quarter. (R. Wright, AFRL/PRSL, (937) 255-5568)

AFOSR THEMES INCLUDE SUPERCONDUCTIVITY AND PLASMA PHYSICS: Two of the top eight research themes selected by the Air Force Office of Scientific Research (AFOSR) are "Directed Electromagnetic Energy" and "Plasma Dynamics." Directed Electromagnetic Energy involves research that enables the introduction of directed energy weapons (DEW) into the Air Force which includes a focus on high-temperature superconducting (HTS) materials for magnets and power generation. Drs. Paul Barnes and Charles Oberly of the Propulsion Directorate's Power Systems Branch (AFRL/PRPS) are performing research in this area. The Plasma Dynamics theme will extend the ongoing research on weakly ionized flows for aircraft. This includes superconducting magnets (Barnes/Oberly) along with drag reduction and glow-discharge modification (Drs. Biswa Ganguly & Charles DeJoseph, also of PRPS). The selection of these topics will ensure the continuation of initiated and ongoing work in these areas of basic research. Dr. Barnes has also coordinated with the Combustion and High Speed Systems Branch (AFRL/PRSC) to integrate superconducting magnet technology to weakly ionized flow work covered under the Plasma Dynamics theme. (P. Barnes, AFRL/PRPS, (937) 255-2923)

NEW SEALS SHOW POTENTIAL FOR HUGE MAINTENANCE SAVINGS: A major breakthrough for reducing maintenance costs has been demonstrated in the Propulsion Directorate's Compressor Aero Research Lab (CARL) facility. A set of redesigned brush seals was installed as a compliant casing surface for the Stage Matching Investigation (SMI) rig. Testing of the redesigned seals was conducted in April 2000, and performance using these seals was compared to results using a smooth casing. The test rig was stalled multiple times and there was clear evidence of rubbing between the rotor and casing. However, no performance penalty resulted from the rubbing, and the pre- and post-rub performance values were identical. Furthermore, the new seals produced more stall margin than the smooth casing as well as statistically identical pressure rise and efficiency (see charts). Currently, an engine is removed from service for overhaul following a rub event. This technology has the

potential to save the Air Force millions of dollars in maintenance expenses by eliminating the need to overhaul engines following a rub event. (G. Bloch, AFRL/PRTF, (937) 255-4738)

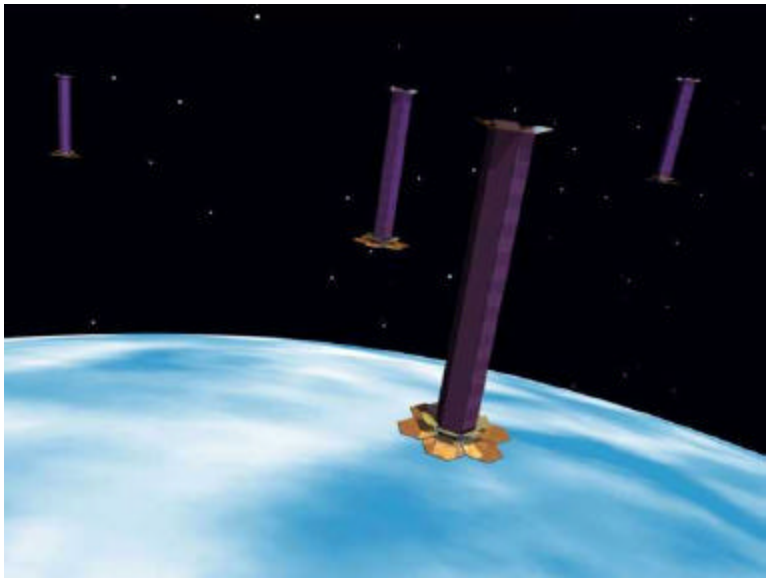


NEW TRAINER TO BE QUALIFIED FOR JP-8+100 FUEL: Personnel from the Propulsion Directorate's Fuels Branch (AFRL/PRSF) are providing technical support to the Flight Training Systems Program Office (ASC/YT) at Wright-Patterson AFB, Ohio. ASC/YT manages the Joint Primary Aircraft Training System (JPATS) Program to develop a new aircraft for training Air Force and Navy pilots. This aircraft, the T-6A Texan II, is the replacement for the Air Force's T-37 and the

Navy's T-34. Air Force T-6As will be located at Air Education and Training Command (AETC) bases that are currently using JP-8+100; consequently, ASC/YT is interested in qualifying the T-6A on JP-8+100 fuel. As the organization that led the development of JP-8+100, PRSF has unequaled expertise on this fuel and issues related to its use. The issues being addressed in the qualification process include materials compatibility as well as health, safety, and environmental aspects of JP-8+100. The addition of the +100 thermal stability additive to JP-8 has been a resounding success, and the additive is now in widespread use in military and commercial aircraft. (W. Harrison, AFRL/PRSF, (937) 255-6601)

The new T-6A Texan II

ACQUISITION STRATEGY FINALIZED FOR TECHSAT 21 PROPULSION: The acquisition strategy for the TechSat 21 Propulsion Subsystem Development was recently finalized. The program will consist of six phases with multiple awards at the start and a downselect to a single contractor at the end of Phase I. Potential bidders were recently invited to demonstrate their capabilities, and during April three contractors demonstrated their pulsed plasma and Hall effect thrusters in the Propulsion Directorate's Electric Propulsion Laboratory. The TechSat 21 Program has the overall goal of developing a constellation of satellites that fly in formation to perform a surveillance mission. This concept is motivated by a desire to reduce the cost and weight of space systems. Micro-propulsion is one of the five major research areas being pursued under the program. The cluster of satellites fly in formation with relatively little propulsive impulse needed to maintain the formation. The main task of the propulsion system is to allow the satellite constellation to be reconfigured or optimized for a particular mission. Propulsion studies will focus on investigations of micro-electric, micro-chemical, and micro-fluidic propulsion systems. The emphasis is on high specific impulse (efficiency), medium and low thrust, and long life/space durability aspects. (L. Quinn, AFRL/PRR, (661) 275-



Artist's concept of a satellite constellation

5630)

CHIP-ON-BOARD TECHNOLOGY FOR COMMON FADEC: A Propulsion Directorate program to develop Chip-On-Board (COB) technology for the Common Full-Authority Digital Engine Control (FADEC) has completed the first phase of testing, down-selected viable components, and completed electronic circuit designs for Phase II testing. Hamilton-Sundstrand and Pratt & Whitney are researching significantly smaller high performance electronic components and their associated FADEC system issues for near-term use on turbine engines. The packaging efficiency of this new technology will enable the Joint Strike Fighter (JSF) engines to meet performance requirements with half the number of Line Replaceable Units (LRUs) required with F119 controls technology. Phase I circuit boards were built with four types of advanced electronic packages, commonly called chip-scale in the industry. These chip-scale packages are only 20 percent larger than the semiconductor die (chip) they retain, and they are one-fifth the size of standard military electronic semiconductor packages. Within the next 5 years, a significant percentage of all high performance electronic components, including PC computer processors, will only be available as a chip-scale device. This program solves a critical size and performance need for the JSF engine control, and COB Common FADEC Technology has been selected for transition into the JSF IFR configuration (2006). This program will facilitate maturation of COB technology, work out system and design issues, and increase performance many times over the F119 control. Phase II tests will begin in September 2000. (K. Semega, AFRL/PRTA, (937) 255-6690)

PROGRESS ON F-16 MAINTENANCE-FREE BATTERY: A Source Selection Team (SST) was recently formed to select two candidate maintenance free batteries to replace the existing vented Ni-Cd (VNC) battery for the F-16 Block 25/30/32 aircraft. The Propulsion Directorate's Battery Branch (AFRL/PRPB) hosted SST members from the F-16 SPO, Ogden Air Logistics Center (ALC), and Naval Surface Warfare Crane Division. Dr. John Erbacher (PRPB) was included in the SST due to his recognized expertise in maintenance-free and electrochemical battery technologies. Two contractors were selected for qualification testing in the next 3 to 4 months, when a final decision will be made based on test results and a cost benefit analysis (CBA) prepared by PRPB. Contract award to the integrating contractor will be announced in May. On a similar recent contractual action, five 17-Ah F-16 prototype batteries are to be produced by GRC International, Inc and SAFT America, Inc for delivery in April 2001. This effort is funded by delivery order under Phase III of the Ni-MH Environmental Aircraft Battery development program. The batteries are a scaled-down version of the 43-Ah technology demonstration battery delivered under the Phase II contract, and will be smaller in size and weight than conventional F-16 VNC batteries or potential maintenance-free replacements. The battery will be available as a preferred spare for the current battery after flight qualification and test. (J. Erbacher, AFRL/PRPB, (937) 255-7770)

BREAKTHROUGH IN POSS POLYIMIDES: Polyimides are one of only a handful of polymers with very high temperature stability (>350°C), but many problems, including lack of processability, have limited their application. Research efforts over the years have shown that increasing the processability always leads to a decrease in high temperature capability. Previous work with other POSS (polyhedral

oligomeric silsesquioxane) polymers has shown that POSS can increase processability without affecting high temperature properties. For the first time, researchers in the Propulsion Directorate's Propulsion Materials Application Branch (AFRL/PRSM) prepared thin Kapton™ polyimide films containing 0, 5, and 10 weight percent of POSS. The samples were cast on glass slides for mechanical analysis and transmission electron microscopy (TEM) analysis. The cured films, which are about 100 nm thick, were tested for high temperature mechanical properties. The films containing POSS showed an improvement in the use temperature of the polymer beyond the glass transition of 400°C. At the same temperature, the sample without POSS loses all mechanical strength. Furthermore, increasing the weight percent of POSS increases this high temperature stability. This is the first demonstration that POSS can improve the use temperature of very high temperature polymers. Work will continue to test the maximum improvement that POSS can impart and how processing is affected. (Capt S. Svejda, AFRL/PRSM, (661) 275-6270)

NEW FATIGUE FRAME PROVIDES LOW COST TEST CAPABILITY: The first airfoil test on the multiaxial high cycle fatigue frame in the Propulsion Directorate's Turbine Engine Fatigue Facility (TEFF) is being performed. The frame was designed and built in conjunction with AdTech Systems Research and was installed in the TEFF during the fall of 1999. This frame is a one of a kind test system that provides the Air Force the ability to test turbine engine blades with multiaxial loading spectrums. This system more closely simulates the actual stresses created by an engine environment than ever before possible in the laboratory. The current test simulates the first torsion resonant mode in a General Electric F100 2nd stage fan blade. At this time, over 30 million cycles have been accumulated on the airfoil. The multiaxial fatigue frame was developed to provide a means of address airfoil fatigue in a laboratory setting. With high cycle fatigue failures accounting for over 50 percent of the Class 1 failures in the Air Force, extensive testing is needed to validate durability and damage tolerance of components. If the loading conditions experienced in operation by gas turbine components can be simulated in a bench environment, a significant amount of testing and validation can be performed inexpensively. This manner of testing represents savings of two orders of magnitude over engine testing and one order of magnitude over spin pit or rig tests. (C. Cross, AFRL/PRTC, (937) 656-5531)

VORTEX-FLAME STUDIES EARN SUPPORT FROM AFOSR IOF: Over the past several years, scientists and engineers in the Propulsion Directorate's Combustion and High Speed Systems Branch (AFRL/PRSC) have been engaged in a multinational study of vortex-flame interactions in an effort to unravel the mysteries of turbulent mixing. A thorough understanding of turbulent mixing and predictive models of turbulence-chemistry interactions are essential to the continued advancement of combustion science and gas turbine combustor development and design. PRSC personnel and on-site contractors with Innovative Scientific Solutions, Inc have worked collaboratively with top talents from École Centrale Paris (ECP) and the University of Bielefeld (Germany) to capture the details of vortex-flame interactions through computational modeling and laser-based experiments. This mutually beneficial relationship has produced numerous publications and presentations, including an award-winning poster featured at the ASME Heat Transfer Photo Gallery Competition. In support of these continuing activities, leaders at AFOSR recently provided PRSC with funding from the International Opportunities Fund (IOF). Dr. James R. Gord will oversee the use of these funds in his continuing role as leader of the vortex-flame project. In addition, Capt Illari Vihinen, who has a working knowledge of French and has

been involved throughout the project, will work with collaborators at ECP and ONERA (The French National Research Aerospace Establishment) to forge a Project Arrangement between the USAF and the French government. (J. Gord, AFRL/PRSC, (937) 255-7431 and Capt I. Vihinen, AFRL/PRSC, (937) 255-8623)

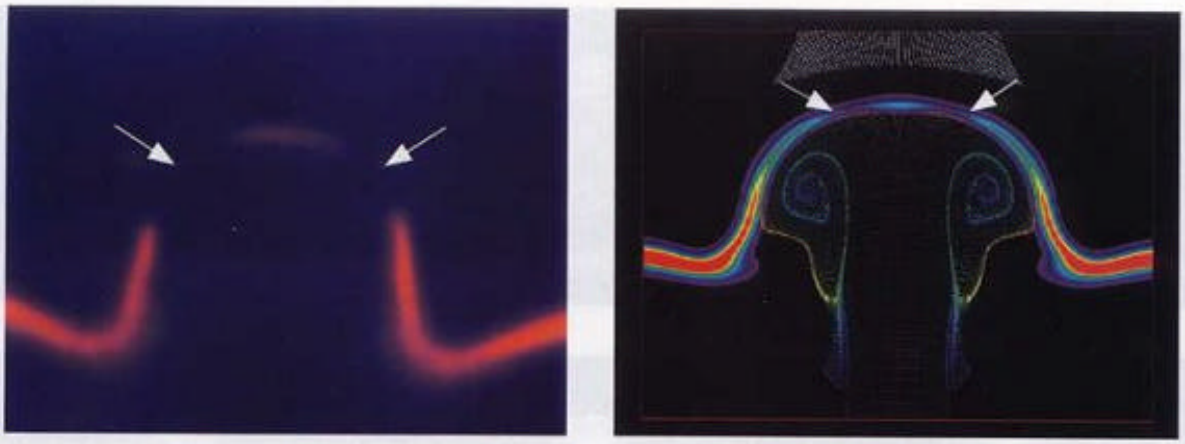


Figure 1. Agreement between Experimental (left) and Computed (right) Flame (OH) Distributions in a Counterflow Burner. Arrows indicate region of local flame extinction; streaklines (color coded with injection location) are shown in the computed image.

Figure 2. Experimental Setup (Red=Flame, Green=Vortex).

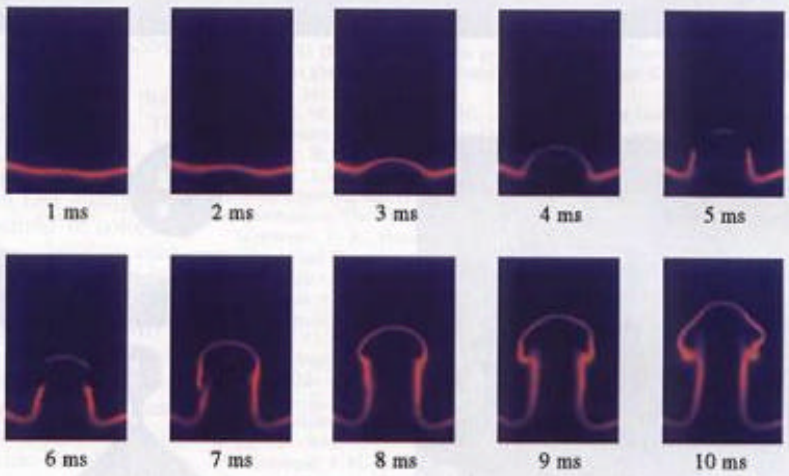


Figure 3. Evolution of the Flame (OH) Distribution in a Counterflow Burner Showing Local Extinction (5 ms), Separation (6 ms), and Reattachment (7 ms).

The award winning ASME Heat Transfer Photo Gallery entry

IHPTET PHASE II JTAGG READIES FOR TEST: Testing of the Integrated High Performance Turbine Engine Technology (IHPTET) Phase II JTAGG (Joint Turbine Advanced Gas Generator) is scheduled to begin in May 2000. The purpose of this initial Phase II JTAGG core test is to demonstrate the mechanical integrity of the components in the gas generator, to establish a performance baseline, and to conduct diagnostic testing. The total estimated run time should not exceed 15 hours. The following

components will be evaluated during the test: (1) single-stage splittered low-pressure (LP) compressor; (2) a two-stage axial-centrifugal high-pressure (HP) compressor; (3) a single-stage cooled HP turbine; and (4) a single-stage LP turbine preceded by uncooled Niobium nozzle vanes. The JTAGG II core test performance will be evaluated in comparison with a pretest analytical model prediction. This model will incorporate measured results from previous component rig tests. The JTAGG test will result in the demonstration of a 27 percent reduction in Specific Fuel Consumption (SFC) versus an IHPTET Phase II goal of 30 percent and a 70 percent increase in horsepower-to-weight ratio versus a goal of 80 percent for IHPTET Phase II. (M. Huffman, AFRL/PRTP, (937) 255-2278)